

Nucleon Helicity in Pion Photoproduction

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Abstract

Pion-photoproduction data is examined to check for the nucleon-helicity conservation predicted by asymptotic QCD. The differential cross section shows agreement with constituent-counting rules, and polarization data is not in disagreement with conservation of nucleon helicity. However large uncertainties in the polarization measurements do not allow a conclusive statement. The helicity amplitudes from a partial-wave analysis are also examined for helicity conservation. While the amplitudes become small as s increases, the s dependence of the helicity-conserving amplitudes is similar to the dependence of the non-conserving amplitudes.

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The application of QCD to the study of nuclear phenomena is an important issue which will be studied by the new generation of several-GeV, high-intensity electron accelerators. The present data for pion photoproduction and deuteron photodisintegration offer a means for a first look at these issues.

The question of the applicability of perturbative QCD to deuteron photodisintegration has been addressed recently by Belz *et al.* who measured the differential cross section for energies up to 2.8 GeV. [1] Their results demonstrate that at $\theta_{cm} = 90^\circ$ the cross section is in good agreement with constituent-counting-rule predictions for incident-photon energies greater than 1.5 GeV. These results are surprising in view of the observation of Isgur and Llewellyn-Smith that perturbative contributions to the cross section are small compared to other processes. [2] Experiments at higher energies may provide further insight into this issue. [3] Another prediction of asymptotic QCD, the conservation of nucleon helicity [4], will be tested by measurements of polarization observables. [5]

Compared to deuteron photodisintegration, there is a much larger set of data for pion photoproduction which can be examined for evidence of nucleon-helicity conservation. The current data from the SAID data base for the differential cross section of the $\gamma p \rightarrow \pi^+ n$ reaction channel is shown in Figure 1a. [6] As has been observed by Anderson *et al.*, the reaction shows agreement with constituent counting rules that predict the cross section should vary as s^{-7} . [7] The agreement extends down to 700 MeV photon energy ($s = 2.2 \text{ GeV}^2$) where baryon resonances are important. Oscillations about the counting-rule prediction are similar to those observed in elastic pp scattering at 90° . [8]

There are three polarization observables for pion photoproduction which vanish if nucleon helicity is conserved. These are the recoil polarization asymmetry P , the target-polarization asymmetry T and the double-polarization observable for polarized photons on a transversely-polarized target H . Plots of these observables at 90° are shown in Fig. 1 for P (Fig. 1b) in the $\gamma p \rightarrow \pi^0 p$ channel and T (Fig. 1c) and H (Fig. 1d) in the $\gamma p \rightarrow \pi^+ n$ channel. The observables become small as s increases, but a definite conclusion is difficult to draw because of large uncertainties in the data. The polarization data extend up to $s \simeq 4 \text{ GeV}^2$. Data in

other pion channels is less extensive, but do not show any different trends.

A more direct means of checking helicity conservation is to look at the helicity amplitudes themselves, as obtained from a partial-wave analysis. A recent partial-wave analysis fits the data up to a photon energy of 2 GeV. [9] The partial-wave results for the helicity amplitudes reflect all of the measured observables for the reaction and should, in principle, be better determined than a polarization observable which can have large uncertainties.

Pion photoproduction is described by eight helicity amplitudes, but with parity conservation only four of the amplitudes are independent. The partial-wave analysis is performed by expanding each of the helicity amplitudes in terms of multipole amplitudes which depend on energy. The amplitudes are varied in a χ^2 fitting procedure to give a best fit to all measured observables. Since the photoproduction data is not sufficiently complete for a fit to the data, the fit is constrained by relations such as Watson's theorem and dispersion relations. Consequently the results depend on the constraining relations and are model dependent. The situation will be improved by new data from CEBAF. [10]

The four nucleon helicities for the $\gamma p \rightarrow \pi^0 p$ reaction channel as determined from partial-wave analysis are shown in Figure 2. Two of the helicity amplitudes, H_2 and H_3 in the notation of Walker [11], should be zero if nucleon helicity is conserved. As s increases, all four helicity amplitudes become small. The helicity conserving amplitudes are somewhat larger than the amplitudes which do not conserve helicity.

In conclusion there is no strong evidence for helicity conservation in the pion-photoproduction data although the polarization data suggests the approach of helicity conservation as energy increases. More data is needed at higher energies. Improved data is also needed in order to reduce the constraints for the partial-wave analysis and extend the analysis to higher energies. The tagged photon beam at CEBAF will provide data with small angular intervals over a large range of angles and energies and will be free of normalization uncertainties associated with much of the present data which has been taken with bremsstrahlung beams.

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FIGURES

FIG. 1. Differential cross section and polarization observables for pion photoproduction at 90° c. m. angle. The data are taken from the SAID data base. [6]. (a) The differential cross section $d\sigma/dt$ versus s for the reaction $\gamma p \rightarrow \pi^+ n$. The dashed line shows the function s^{-7} for reference. (b) P, the recoil-polarization asymmetry for the $\gamma p \rightarrow \pi^0 p$ reaction, c) T, the target-polarization asymmetry for the $\gamma p \rightarrow \pi^+ n$ reaction, and d) H, the double-polarization observable for polarized photons on a transversely-polarized target for the $\gamma p \rightarrow \pi^+ n$ reaction. The polarization observables are equal to zero if the reaction conserves nucleon helicity. The solid line shows the prediction SM95 from the partial-wave analysis of Arndt et al. [9]

FIG. 2. Helicity amplitudes for pion photoproduction versus s for the $\gamma p \rightarrow \pi^0 p$ reaction at 90° c.m. angle as determined in the SM95 solution of the analysis of Arndt *et al.* [9]. (a) H_1 , (b) H_2 , (c) H_3 and (d) H_4 . Solid (dashed) curves give the real (imaginary) parts of the amplitudes. If the reaction conserves helicity, H_2 and H_3 should equal zero.

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